

SEMICONDUCTOR DEVICE AND METHOD AND APPARATUS  
FOR MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

5 FIELD OF THE INVENTION:

The present invention relates to a semiconductor device and a method and apparatus for manufacturing the same and, more particularly, to a Cu diffusion preventive insulating layer in an interlevel insulating film formed  
10 between a Cu interconnection and a metal interconnection on it.

DESCRIPTION OF THE PRIOR ART:

In the IC manufacturing field, as the operation speed and integration degree of devices increase, the device  
15 design rule decreases. As the device feature size decreases, the interconnection size and the gap between interconnections also decrease, so the interconnection resistance and the parasitic capacitance between interconnections tend to increase.

20 When the interconnection resistance or parasitic capacitance between interconnections increases, the RC time constant increases, and the signal propagation speed decrease to pose a problem in increasing the operation speed of the device. The parasitic capacitance between  
25 interconnections increases in proportion to the area of

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In recent years, various types of interlevel insulating films with low dielectric constants, e.g., an SiOF film with a lower relative dielectric constant than that of a conventional SiO<sub>2</sub> film, has been studied in order to decrease the capacitance between interconnections. To decrease the interconnection resistance, a technique which uses as an interconnection material Cu with a lower resistivity than that of Al conventionally used widely as the interconnection material, and products as a result of this technique have become popular.

When Cu is used as the interconnection material, since it is difficult to micropattern Cu by dry etching, a damascene interconnection structure as shown in Fig. 1 is usually used widely. A damascene interconnection is formed in the following manner. A trench 20 is formed in an interlevel film 6, and is filled with a barrier metal 10 and Cu. Excessive Cu and barrier metal on the insulating film are removed by CMP, thus forming a Cu interconnection 12.

If an interlevel insulating film is to be formed after formation of the damascene interconnection, as Cu easily reacts with  $\text{SiO}_2$  and diffuses, an SiN film 52 is usually formed as a diffusion preventive insulating film 5 on Cu to a thickness of about 50 nm to 100 nm in accordance with parallel-plate plasma CVD by using  $\text{SiH}_4$ ,  $\text{NH}_3$ , and  $\text{N}_2$ , and after that an insulating film 20 of  $\text{SiO}_2$  or the like is formed.

In this case, SiN not only prevents Cu diffusion but 10 also prevents the Cu surface from being exposed to the  $\text{SiO}_2$  etching or  $\text{O}_2$  resist ashing atmosphere when, e.g., a via hole is to be formed on the Cu damascene interconnection, so it also serves as an etching stop layer for  $\text{SiO}_2$ . In this manner, the SiN film 52 formed on 15 the Cu surface must prevent Cu diffusion and serve as an etching stop layer.

Problems to be solved by the present invention are as follows.

1. Usually, when a SiN film is to be formed on a Cu 20 surface, as the film formation temperature is about 400 degrees of Celsius thermometer, as the substrate temperature increases, aggregation of Cu tends to occur, and the morphology of the Cu surface degrades. Hence, a diffusion preventive insulating layer in which aggregation 25 of Cu is suppressed is necessary.

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2. One of methods of suppressing aggregation of Cu is to decrease the film formation temperature. When the film formation temperature is decreased, SiN forms a low-density insulating film. If the insulating film has a low density, the etching selectivity with respect to SiO<sub>2</sub> decreases, and the SiN film cannot serve as an etching stop layer. For this reason, a dense film for maintaining the etching selectivity with respect to the insulating film is necessary as a diffusion preventive layer.

#### SUMMARY OF THE INVENTION

The present invention has been made to solve the above problems of the prior art, and has as its object to provide a semiconductor device with an interlevel insulating film which can suppress aggregation of Cu and has a sufficiently high etching selectivity with respect to an insulating film, and a method and apparatus for manufacturing the same.

In order to achieve the above object, according to the first main aspect of the present invention, there is provided a semiconductor device in which an interlevel insulating film formed between a Cu interconnection formed by damascene and an upper metal interconnection layer formed on said Cu interconnection has a multilayered structure made of a Cu diffusion preventive insulating layer and another insulating film, wherein said Cu

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diffusion preventive insulating layer has a multilayered structure made of not less than two layers.

The semiconductor device according to the first main aspect has the following subsidiary aspects.

5       The Cu diffusion preventive insulating layer is formed by CVD so as to be made up into a multilayered structure.

10       The Cu diffusion preventive insulating layer has a multilayered structure made up of a first Cu diffusion preventive insulating film formed by CVD at a temperature of less than 350°C and a second Cu diffusion preventive insulating film formed by CVD at a high temperature of not less than 350°C and not more than 450°C.

15       An oxide layer on a Cu surface, which is formed between said Cu diffusion preventive insulating layer and said Cu interconnection, is reduced in order to improve adhesion properties of said Cu diffusion preventive insulating layer.

20       The first Cu diffusion preventive insulating film is an insulating film not containing O, and the first Cu diffusion preventive insulating film not containing O is one film selected from the group consisting of an SiN film, SiC film, SiCN film, and organic film.

25       A dry etching selectivity of said second Cu diffusion preventive insulating film to said interlevel insulating

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film formed on said second Cu diffusion preventive insulating film is not less than 1 : 10.

In order to achieve the above object, according to the second main aspect of the present invention, there is provided a semiconductor device manufacturing method of forming an interlevel insulating film into a multilayered structure made of a Cu diffusion preventive layer and another insulating film between a Cu interconnection formed by damascene and an upper metal interconnection layer on said Cu interconnection, comprising forming at least two stacked Cu diffusion preventive insulating layers as said Cu diffusion preventive layer.

The semiconductor device manufacturing method according to the second main aspect has the following subsidiary aspects.

The Cu diffusion preventive layer is formed into at least two stacked layers by CVD.

The Cu diffusion preventive layer is formed by forming a first Cu diffusion preventive insulating film by CVD at a low temperature of less than 350°C, and forming a second Cu diffusion preventive insulating film by CVD at a high temperature of not less than 350°C and not more than 450°C.

The Cu diffusion preventive layer forming step comprises reducing a Cu oxide layer formed on said Cu

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interconnection and forming said Cu diffusion preventive layer in order to improve adhesion properties of said Cu diffusion preventive insulating layer.

In this manner, when the first insulating film is  
5 formed on the Cu interconnection at a low temperature of less than 350°C so aggregation of Cu is suppressed, and the second insulating film is formed at a high temperature of not less than 350°C and not more than 450°C, a Cu diffusion preventive insulating layer with a multilayered  
10 structure, which functions highly as an etch stop layer, can be formed.

The first effect of the present invention is that it can suppress aggregation of Cu in the Cu interconnection. Aggregation of Cu is suppressed because the first  
15 insulating film is formed at a low temperature of less than 350°C.

The second effect of the present invention is that it can improve the etching selectivity of the insulating film to the Cu diffusion preventive insulating layer (e.g.,  
20 SiO<sub>2</sub> and SiN). The reason is that, since a Cu diffusion preventive insulating layer has a multilayered structure made of not less than two layers, and further the second Cu diffusion preventive insulating film is formed at a high temperature of not less than 350°C and not more than  
25 450°C, such a Cu diffusion preventive insulating layer as

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being denser and having a better film quality than a Cu diffusion preventive insulating layer formed at a temperature of less than 350°C can be formed.

#### BRIEF DESCRIPTION OF THE DRAWINGS

5 Fig. 1 is a sectional view for describing a prior art; and

Figs. 2A to 2K are sectional views showing a process of manufacturing a semiconductor device according to the present invention in the order of its steps.

#### 10 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A semiconductor device and a method of manufacturing the same according to the first embodiment of the present invention will be described with reference to the accompanying drawings.

15 Figs. 2A to 2K show a process of manufacturing a semiconductor device according to the present invention in the order of its steps.

First, as shown in Fig. 2A, an SiO<sub>2</sub> insulating film 6 is formed on a silicon substrate 4 with a device element to a thickness of 500 nm by plasma CVD. Subsequently, a photoresist 8 is applied to the SiO<sub>2</sub> insulating film 6, and a trench interconnection pattern is formed by photolithography.

As shown in Fig. 2B, the insulating film 6 is etched 25 by dry etching to form a trench, and the photoresist 8 is

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FOI b7D b7E b7F b7G b7H b7I b7J b7K b7L b7M b7N b7O b7P b7Q b7R b7S b7T b7U b7V b7W b7X b7Y b7Z



removed by O<sub>2</sub> dry ashing and wet etching. After that, Ta  
10 is formed as a barrier metal to a thickness of 50 nm,  
and a Cu film is formed by sputtering to a thickness of  
100 nm as a seed layer for Cu plating on the entire  
5 surface of the silicon substrate 4 (see Fig. 2C).

The trench is filled with Cu 14 by electrolytic  
plating, and Cu is annealed at 400°C. Then, as shown in  
Fig. 2D, the Cu 14 and barrier metal 10 on the insulating  
film 6 are removed by CMP, thus forming the Cu inter-  
10 connection 12.

As shown in Fig. 2E, by using a single-wafer type  
parallel-plate CVD apparatus, a diffusion preventive  
insulating layer SiN as a first insulating film 16 is  
formed to a thickness of 20 nm by low-temperature film  
15 formation with a film formation temperature of 300°C, an  
SiH<sub>4</sub> flow rate of 50 sccm, an NH<sub>3</sub> flow rate of 30 sccm, an  
N<sub>2</sub> flow rate of 2,000 sccm, a film formation pressure of  
4 Torr, and an RF power of 400 W. After that, by using  
another film formation chamber, a diffusion preventive in-  
20 sulating layer SiN as a second insulating film 18 is  
formed to a thickness of 30 nm by high-temperature film  
formation with a film formation temperature of 400°C, an  
SiH<sub>4</sub> flow rate of 50 sccm, an NH<sub>3</sub> flow rate of 30 sccm, an  
N<sub>2</sub> flow rate of 2,000 sccm, a film formation pressure of  
25 4 Torr, and an RF power of 400 W.

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As shown in Fig. 2F, a 500-nm thick SiO<sub>2</sub> film is formed as an insulating film 20 by plasma CVD. The first and second insulating films 16 and 18 and the insulating film 20 make up the interlevel insulating film.

5           How to form a via hole in the interlevel insulating film comprised of the insulating film 20 and the like will be described. As shown in Fig. 2G, a pattern for forming a via hole is formed with a photoresist 22 by photolithography, and the SiO<sub>2</sub> film as the insulating film 20 is etched by dry etching using C<sub>4</sub>F<sub>8</sub>, Ar, and O<sub>2</sub> (see Fig. 2H). In this case, the etching conditions are determined such that the etching selectivity of the Cu diffusion preventive insulating film of the insulating film 20 to that of the second insulating film 18 is 10 or more, so the Cu diffusion preventive insulating film of the second insulating film 18 serves as the etching stop layer when etching the insulating film 20.

As shown in Fig. 2I, the photoresist 22 is removed by O<sub>2</sub> ashing and resist peeling technique using a wet etchant. At this time, oxidation and etching of the first and second insulating films 16 and 18, which occur when the surface of a Cu interconnection 12 is exposed to an O<sub>2</sub> plasma and the like, are prevented.

As shown in Fig. 2J, the Cu diffusion preventive  
25 insulating layer comprised of the first and second

As shown in Fig. 2K, a TiN film 11 is formed to a thickness of 50 nm, and thereafter a W (tungsten) film 32 is formed to a thickness of 700 nm. The W film 32 fills the via hole 30, and the excessive W film 32 and TiN film 11 on the interlevel insulating film 20 are removed by CMP, thus forming a via contact with respect to the Cu interconnection 12.

10 In the above case, SiN is used to form the diffusion preventive insulating layer comprised of the first and second insulating films 16 and 18. Alternatively, an insulating film such as a SiC, SiCN, or organic film which does not react with Cu and thus serves to prevent  
15 diffusion of Cu may be employed. To form the insulating film 20, SiO<sub>2</sub> is used. Alternatively, an insulating layer, e.g., a porous silica, organic, HSQ, or MSQ film, with a lower relative dielectric constant than that of SiO<sub>2</sub> may be used.

Subsequently, by using a parallel-plate CVD apparatus, a plasma pre-process is performed with a process temperature of 300°C, an N<sub>2</sub> flow rate of 500 sccm, an NH<sub>3</sub>

flow rate of 500 sccm, a pressure of 4 Torr, and an RF power of 200 W in order to reduce the oxide layer on the Cu surface. After that, a diffusion preventive insulating layer SiN as a first insulating film 16 is formed to a thickness of 20 nm with the same conditions as those of the first embodiment.

Subsequently, by using another CVD apparatus, a diffusion preventive insulating layer SiC as a second insulating film 18 is formed to a thickness of 30 nm with a film formation temperature of 400°C.

An SiO<sub>2</sub> layer is formed to a thickness of 500 nm by the parallel-plate plasma CVD apparatus, and an insulating film 20 is formed on the Cu interconnection 12.

In this case, the pre-process for reducing the Cu oxide layer is performed at 300°C. It suffices as far as aggregation of Cu is suppressed at less than 300°C. Although a plasma pre-process is performed, annealing in a reducing gas atmosphere of NH<sub>3</sub> or H<sub>2</sub> may be performed instead. Although N<sub>2</sub> and NH<sub>3</sub> are used as gases for the pre-process, a single-gas atmosphere of H<sub>2</sub> or NH<sub>3</sub>, or a gas mixture atmosphere of N<sub>2</sub>, H<sub>2</sub> and NH<sub>3</sub> may be used instead. The gas type is not particularly specified as far as it can reduce the oxide layer on the Cu surface. A process chamber for performing the plasma pre-process may be provided independently of the SiN film formation

chamber.

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In the above embodiments, SiN is used to form the Cu diffusion preventive insulating layer of the first insulating film 16, and SiC is used to form the Cu diffusion preventive insulating layer of the second insulating film 18. Alternatively, an SiCN, organic, or SiON film may be used as each insulating film. The diffusion preventive layers formed of the first and second insulating films 16 and 18 need not have the same film composition, and are not particularly specified as far as they have an etching selectivity of a predetermined value or more with respect to the insulating film 20. In the above embodiments, a Cu diffusion preventive insulating layer with a double-layer structure is formed. Alternatively, a multilayered structure of three or more layers may be employed. The present invention is not particularly specified in this respect as well.

As the manufacturing apparatus, the CVD apparatus is used to form the first insulating film 16 at a temperature of about 300°C and the second insulating film 18 at a temperature of about 400°C. Except for that, the arrangement of the manufacturing apparatus can be the same as that of a conventional apparatus.